

GOVERNMENT
1132-1
186538
13P

FEASIBILITY STUDY OF A SYNTHESIS PROCEDURE FOR ARRAY FEEDS TO IMPROVE RADIATION PERFORMANCE OF LARGE DISTORTED REFLECTOR ANTENNAS

SEMIANNUAL STATUS REPORT

submitted to

NASA Langley Research Center

for

Grant No. NAG-1-859

by

W.L. Stutzman
K. Takamizawa
P. Werntz
J. LaPean
B. Shen

Virginia Polytechnic Institute and State University
Bradley Department of Electrical Engineering
Blacksburg, Virginia 24061-0111

SATCOM Report No. 93-15

October 1993

N94-14501

Unclass

G3/32 0186538

(NASA-CR-194491) FEASIBILITY STUDY
OF A SYNTHESIS PROCEDURE FOR ARRAY
FEEDS TO IMPROVE RADIATION
PERFORMANCE OF LARGE DISTORTED
REFLECTOR ANTENNAS Semiannual
Status Report (Virginia
Polytechnic Inst. and State Univ.)
13 p

wls\semiann1
10/11/93

Table of Contents

1. INTRODUCTION	1
2. PROGRESS	2
2.1 Dual Reflector Antenna - Type 1 Antenna	2
2.2 Tri-Reflector Antenna - Type 2 Antenna	2
2.3 Spherical Reflectors	2
2.4 Optimization	2
3. PUBLICATIONS	10
3.1 Recent Publications	10
3.1.1 Conferences	10
3.1.2 Papers	10
3.1.3 Reports	10
3.2 Planned Publications	10
3.2.1 Conferences	10
3.2.2 Papers	10
3.2.3 Theses, dissertations, reports	11

1. INTRODUCTION

The manpower on this effort was reduced during this reporting period. Activity was focused on documentation. In this introduction we summarized progress in the past six months.

The Type 1 antenna is complete and documentation is in final phases. The Type 2 antenna design is complete and a journal article was prepared and was accepted for publication in IEEE Transactions on Antennas and Propagation. The spherical antenna configurations are complete and a journal article will appear in the June 1993 issue of IEEE Transactions on Antennas and Propagation. In addition, a patent for the spherical antenna is being pursued. The final current activity is that of optimization techniques and they are approaching completion as well. See Chapter 3 for a summary of publications.

The Tri-Reflector synthesis code (TSAP) was put into user friendly format. A user's guide (Report 93-13) was written and distributed to LaRC.

Work continues on EASY7. EASY7 is a user friendly code used to create an input file to GRASP7.

2. PROGRESS

2.1 Dual Reflector Antenna - Type 1 Antenna

The Type 1 canonical Cassegrain reflector antenna scanning effort is now being documented. This documentation takes the form of a thesis, Beam Scanning in Cassegrain Reflector Antenna Systems by Subreflector Motion, and an associated journal article. This work is expected to be completed during October-November 1993.

2.2 Tri-Reflector Antenna - Type 2 Antenna

The detailed documentation (Report 93-7) was completed and sent to LaRC. A journal article on this was accepted recently.

The software (TSAP) was made user friendly and documented in Report 93-13. Jim LaPean visited LaRC on August 5, 1993 to demonstrate TSAP.

2.3 Spherical Reflectors

The detailed report on spherical main reflectors was finished (Report 93-14) and will be distributed to LaRC. One journal article appeared in the June issue of IEEE Trans. on Ant. and Prop.. Two other articles are in preparation.

2.4 Optimization

Optimization techniques to improve the scan performance of multiple reflector antennas are in the final stage of development. Documentation of scan optimization techniques is being written. The following is a summary of recent developments.

Beam scanning in the focused systems such as reflector antennas are accomplished by the displacement of the feed away from the focal point. Feed displacement can be accomplished by physically translating the feed antenna away from the focus, or by translating and rotating one or more reflectors in multiple reflector antenna systems to displace the feed image. Displacement of the feed introduces the necessary linear phase tilt in the aperture field to scan the beam. However, the displacement of the feed also degrades the radiation pattern of the reflector with increasing

scan angle. In terms of aperture fields, performance degradation occurs because of the following four undesirable effects:

- a. Increase in aperture phase error.
- b. Reduction in aperture illumination efficiency
- c. Increase in spillover
- d. Increase in the cross polarized component of the field.

Studies of these four effects in paraboloidal reflector antennas show that all four effects are inter-related. Unfortunately, when one of the effects is improved, the other effects often degrade. Thus, the optimization of reflectors for beam scanning must incorporate the trade-offs in the above effects.

The synthesis techniques developed for Type 1 and Type 2 systems use only the phase error because the beam degradation is the most sensitive to the phase error. To optimize the scan capability of these systems it is necessary to improve the aperture illumination efficiency and spillover efficiency while keeping the aperture phase error to minimum.

The optimization technique developed for improving scan capability of Type 1 systems is implemented as two step process. The first step is reflector displacement optimization. In this process the displacement of secondary reflector is determined for scan of the beam in the desired direction. The technique determines the required location of the secondary reflector while maximizing the reflector illumination efficiency and reducing the aperture phase error. Emphasis is placed more on the illumination efficiency rather than phase error in this step. The second step in beam scanning optimization is the reflector shape optimization. This step is necessary to compensate for some of the phase error introduced from the first step. This step, however, cannot be applied unless good illumination of reflectors has been achieved using the first step.

Reflector Displacement Optimization.

Beam scanning in the Type 1 system is accomplished by translation and rotation of the secondary reflector. The displacements are determined using ray direction error, which is directly

related to the aperture phase error. A detailed analysis of the original Type 1 configuration reveals that beam degradation during scan occurs primarily due to spillover and reduction in aperture illumination efficiency. Thus, the scan capability of Type 1 system can be improved by reducing the spillover and improving the aperture illumination efficiency while minimizing the aperture phase error.

A new technique developed for the determination of required secondary reflector displacements is similar to the technique derived by Kitsuregawa. In Kitsuregawa's method, a secondary reflector surface which has zero phase error for a given beam scan angle and a primary reflector surface is derived first. This secondary reflector surface is determined based on the Snell's law and total path length similar to the method used in the determination of tertiary reflector shape in the Type 2 configuration. This reflector is referred as the "exact" secondary reflector surface. The surface of secondary reflector for unscanned beam (a hyperboloid in the case of the Type 1 configuration) is then fitted to the exact secondary reflector using translational displacements in three dimensions and rotational displacements in two axis. The required translational and rotational displacements are determined such that the difference in the shapes of the hyperboloidal reflector for the unscanned beam and the exact secondary reflector are minimum. It has been shown that resulting configuration is inferior in beam scanning capabilities to the Type 1 configuration.

The new technique developed is an extension of Kitsuregawa's method. In this technique, the parent hyperboloid of the secondary reflector rather than the hyperboloidal reflector for unscanned beam is fitted to the exact secondary reflector using translational displacement in three dimensions and rotational displacement in three axis. Fitting the parent hyperboloid to the exact reflector results in increased dimension of the secondary reflector. The magnitude of increase in the reflector size is a function of range in the desired scan angle.

In Kitsuregawa's method and in the Type 1 synthesis the secondary reflector is allowed to rotate about x-axis and y-axis. In the new technique, an additional rotation of the secondary

reflector about z-axis is also allowed. The additional axial rotation of the secondary reflector is not necessary, as demonstrated by the Type 1 system. However, this additional degree of freedom significantly improves scanning in the planes other than the plane of offset (i.e. scanning in all directions except $\phi = 0^\circ$ and $\phi = 180^\circ$ planes). The third rotational displacement also reduces the total translational displacement required. However, this additional axial rotation also complicates the mechanical implementation of secondary reflector motion, and it may not be suitable for applications with limited weight and power requirements. It is expected that this third rotational displacement of reflector can also be implement for the tertiary reflector of the Type 2 system to improve its scan capability.

Reflector Shape Optimization

The scan capability of reflector antennas can be further improved by the introduction of reflector surface shape optimization. In this step, the surfaces of the reflector antennas are modified from the original shape by a function $\delta_z(x, y)$. The resulting reflector surface is given by

$$z(x, y) = z_0(x, y) + \delta_z(x, y)$$

where $z_0(x, y)$ is the surface of the original undistorted reflector surface. The effect of the small changes in the surface of reflector ($|\delta_z| < 1\lambda$) is primarily in the phase of the aperture fields. The effect in the amplitude of the aperture fields is negligible. Thus, the reflector surface shape optimization can be implemented to minimize the aperture phase error that exists after the reflector displacement optimization.

To solve for the function δ_z it is necessary to expand the function in a series. A truncated form of Zernike polynomial was introduced last year. The Zernike polynomial is a infinite sum of orthogonal polynomials defined over a unit circle. It was determined that the truncated Zernike polynomial cannot represent the necessary changes in the shape of the reflector surface unless a sufficiently large number of terms are included in the series.

A new polynomial series was introduced to overcome the problem with Zernike polynomial. It is similar in form to truncated Zernike polynomial but with a few additional terms. It was derived with an assumption that the necessary changes in the reflector surface shape are similar to the shapes of coma and astigmatism aberrations in the aperture fields. The new series used is

$$\begin{aligned}\delta_z(x,y) = & A_1 + A_2\rho\cos\phi + A_3\rho^2 + A_4\rho^2\cos\phi + A_5\rho^2\cos2\phi \\ & + A_6\rho^3 + A_7\rho^3\cos\phi + A_8\rho^3\cos2\phi \\ & + A_9\rho^4 + A_{10}\rho^4\cos\phi + A_{11}\rho^4\cos2\phi\end{aligned}$$

where

$$\rho = \sqrt{x^2 + y^2}$$

$$\phi = \tan^{-1}(x/y)$$

The terms associated with the coefficients A_1 , A_4 and A_{10} are new terms which are not available in Zernike Polynomials.

Results

The reflector displacement optimization and the reflector surface shape optimization were applied to the Type 1 reflector configuration for the NASA test article. A profile of the reflector antenna geometry for unscanned beam is shown in Fig. 2.4-1. The diameter of the secondary reflector must be increased to 2.4 m x 2.2 m from the original 1.8 m x 1.6 m. The electromagnetic analysis of the improved Type 1 system was conducted with GRASP7 for operation in 20 GHz which corresponds to the primary reflector projected aperture diameter of 710λ . GO/GTD analysis was used for the secondary reflector fields and PO analysis was used

for the primary reflector fields. The effects of secondary reflector blockage are not included in the analysis. Samples of gain, cross polarization levels, and the side lobe levels are shown in table 2.4-1.

The results show that the improved Type 1 system achieves beam scanning over ± 1 degree in any ϕ direction with less than 1 dB gain loss. The cross polarization levels which are unusually low is due to the choice of feed antenna used in the calculation. The number must be interpreted as the cross polarization induced by the geometry of the system. The actual cross polarization levels depend on the choice of the feed antenna used in the system.

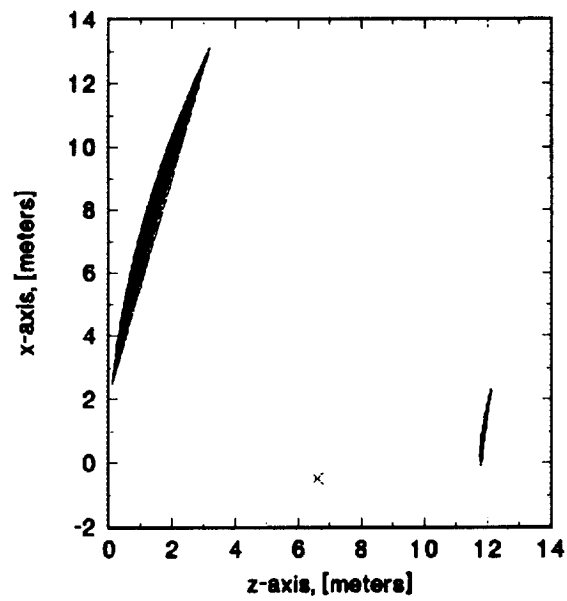


Figure 2.4-1 Profile of improved Type 1 configuration for NASA test article.

Table 2.4-1

Calculated gain, cross polarization levels, and side lobe levels of improved Type 1 system for NASA test article operated at 20 GHz.

Gain

θ scan	ϕ scan				
	0°	45°	90°	135°	180°
0.0°	65.04 dB				
0.5°	65.11 dB	65.08 dB	65.03 dB	64.99 dB	64.98 dB
1.0°	64.45 dB	65.02 dB	65.01 dB	64.81 dB	64.74 dB
1.5°	58.24 dB	64.99 dB	64.80 dB	63.92 dB	63.12 dB

Side Lobe Level

θ scan	ϕ scan				
	0°	45°	90°	135°	180°
0.0°	-31.30 dB				
0.5°	-30.01 dB	-30.50 dB	-31.15 dB	-31.16 dB	-31.42 dB
1.0°	-27.32 dB	-30.23 dB	-30.75 dB	-31.19 dB	-31.54 dB
1.5°	-16.84 dB	-29.23 dB	-31.04 dB	-22.45 dB	-23.84 dB

Cross Polarization Level

θ scan	ϕ scan				
	0°	45°	90°	135°	180°
0.0°	-74.07 dB				
0.5°	-57.70 dB	-55.27 dB	-55.03 dB	-55.52 dB	-57.97 dB
1.0°	-51.59 dB	-48.80 dB	-49.04 dB	-49.51 dB	-51.90 dB
1.5°	-48.70 dB	-45.58 dB	-46.06 dB	-46.40 dB	-48.49 dB

3. PUBLICATIONS

3.1 Recent Publications

3.1.1 Conferences

- (1) B. Shen and W.L. Stutzman, "Beam Efficiency Evaluation of Large Reflector Radiometer Antennas," URSI Meeting, Jan. 1993.
- (2) B. Shen and W.L. Stutzman, "Methods to Improve the Aperture Efficiency and Simplify the Mechanical Motion of Spherical Main Reflector Scanning Antennas," URSI Meeting, Jan. 1993.

3.1.2 Papers

- (1) B. Shen and W.L. Stutzman, "Design of scanning spherical tri-reflector antennas with high aperture efficiency," IEEE Trans. on Ant. and Prop., June 1993.
- (2) P.C. Werntz, W.L. Stutzman, and K. Takamizawa, "A high gain tri-reflector antenna configuration for beam scanning," to appear in IEEE Trans. on Ant. and Prop..

3.1.3 Reports

- (1) Paul Werntz, "A High Gain Tri-Reflector Antenna Configuration for Beam Scanning," Ph.D. Dissertation, Virginia Tech Report No. EE SATCOM 93-7, 321 pp., May 1993.
- (2) Bing Shen, "Multiple Reflector Scanning Antennas," Ph.D. Dissertation, Virginia Tech Report No. EE SATCOM 93-14, 101 pp., July 1993.
- (3) Paul Werntz, "Tri-Reflector Synthesis and Analysis Package (TSAP) User's Guide," Virginia Tech Report No. EE SATCOM 93-13, July 1993.

3.2. Planned Publications

3.2.1 Conferences

3.2.2 Papers

- (1) B. Shen and W.L. Stutzman, "Beam efficiency evaluation for large antennas," to be submitted.

- (2) B. Shen and W.L. Stutzman, "Design of a Scanning Spherical Tri-Reflector Antenna with a Mirror," to be submitted.
- (3) J.W. LaPean and W.L. Stutzman, "Wide Scanning Dual Reflector Antennas Using a Moving Subreflector," to be submitted.
- (4) K. Takamizawa and W.L. Stutzman, "Optimization of Multiple Reflector Antenna Performance Under Parameter Constraints," to be submitted.

3.2.3 Theses, dissertations, reports

- (1) J.W. LaPean, "Beam Scanning in the Cassegrain Antenna System Using a Moving Subreflector," Master's Thesis, Virginia Tech, 1993.
- (2) K. Takamizawa, "Optimization of Multiple Reflector Antenna Performance Under Parameter Constraints," Ph.D. dissertation, Virginia Tech, 1993.